circulation through the skin, allowing heat loss. In this respect, our findings suggest that dissipation of body heat may occur from the entire skin surface or from local regions of it, rather than from specific peripheral areas such as the flippers.

G. S. MOLYNEUX, M. M. BRYDEN
School of Anatomy,
University of Queensland,
St. Lucia, 4067, Australia

References and Notes

1. S. von Schumacher, *Arch. Mikrosk. Anat. Entwicklungsmech.* **71**, 58 (1908).
2. F. J. Tarasoff and H. D. Fisher, *Can. J. Zool.* **48**, 821 (1970).
3. G. S. Molyneux, in *Biology of the Skin and Hair Growth*, A. G. Lyne and B. F. Short, Eds. (Angus & Robertson, Syndey, 1965), p. 591.
4. M. E. D. Webster and K. G. Johnson, *Nature (Lond.)* **201**, 208 (1964).
5. J. S. Hart and H. D. Fisher, *Fed. Proc.* **23**, 1207 (1964).
6. M. M. Bryden, *Nature (Lond.)* **203**, 1299 (1964).
7. P. F. Scholander, *Hvalradets Skr.* **22** (whole issue) (1940).
8. C. Ray and M. S. R. Smith, *Zoologica* **53**, 33 (1968).
9. E. R. Clark and E. L. Clark, *Am. J. Anat.* **54**, 229 (1934).
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Color Vision and Brightness Discrimination in Two-Month-Old Human Infants

Abstract. *A red or white bar, embedded in a white screen, was systematically varied in intensity. Infants consistently located and stared at the white bar unless it closely matched the screen in intensity. They also stared at* all *intensities of the* red *bar, presumptively including the red-white brightness match, and hence must have some form of color vision.*

If an organism can discriminate a colored light from a "white" light, solely on the basis of their difference in wavelength composition, then the organism is said to have color vision (*1*). In this report we present evidence that 2-month-old human infants can make such a discrimination.

It has been demonstrated several times that infants can discriminate between objects or lights having different wavelength compositions (*2*). The difficulty lies in proving that the discriminations are being made on the basis of wavelength (or chromatic) differences rather than just on the basis of infant luminance (or brightness) differences.

Infants' spectral sensitivity curves—the relative sensitivity to different wavelengths of light—are known to be quite similar to those of human adults, especially in the middle- and long-wave regions of the spectrum (*3*). Hence a heterochromatic brightness match made by a color-normal adult provides a good first approximation to the brightness match for an infant, but does not guarantee the complete elimination of brightness differences.

Our approach toward eliminating the brightness cue was to use a long wavelength (red) light and test the infant's capacity to discriminate it from a white light. We started from the adult red-white brightness match, and explored a *range* of relative intensities centered around this match. We explored this range in small enough intensity *steps* to ensure that in at least one case the red and white lights would have to be indiscriminable in brightness for the infant. If the infant could discriminate between red and white for *all* of the relative intensities used (including, then, whichever one is a brightness match), the infant must have color vision.

It is extremely likely that, for red light, the range ±0.4 log unit around the adult's red-white brightness match will somewhere contain each individual infant's red-white brightness match (*3*). Thus, we chose intensities about 0.4 log unit above and below the adult brightness match as the end points of the range, for a total range of a little more than 0.8 log unit.

In order to choose the size of the intensity steps needed for detailed examination of the 0.8 log unit range, we decided to leave color aside temporarily, and find out how sensitive the infant is to small brightness differences, using only white lights.

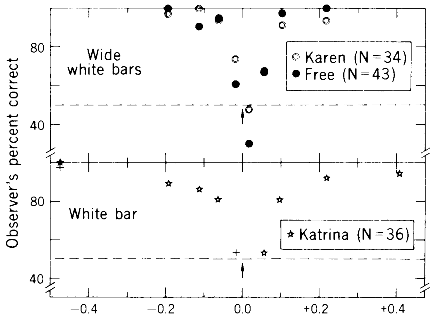

Fig. 1. (Top) Brightness discrimination functions in two 2-month-old human infants, Karen and Free. Zero on the abscissa represents the intensity at which a set of wide white bars matched a surrounding white screen. Both infants are sensitive to very small intensity differences. (Bottom) Same as top, but the four wide bars were replaced by a single narrower white bar, and a third infant, Katrina, was used. The brightness discrimination function is broadened somewhat. The plus marks (+) indicate data collected during the last day's session.

In this experiment, each of two 2-month-old female infants (*4*) was held 34.5 cm from a 0.1 log mlam white screen of a color temperature of about 2650°K. An observer watched the infant's face through a peephole in the center of the screen. On either side of the peephole (centered 16.5 cm, or 24.2°, laterally) four vertical rectangular openings (8.4 by 1.2 cm, or 13.9° by 2.0°) were cut in the screen. The openings formed four cycles of a square-wave grating of about 0.25 cycle/deg.

Diffusing screens were located about 10 cm behind the openings, and could be independently back-illuminated. On every trial, the back illumination was arranged to make the light coming through one set of openings match the screen in brightness and hue, so that the screen looked virtually homogeneous (to us) on that side of the peephole. The light from behind the other set of openings could be set to a variety of intensities, above or below that of the screen, and formed (for us) a set of readily visible bars. The intensity of these bars, and the side on which they were presented, varied randomly across trials.

When the intensity of the bars differs enough from that of the screen, an infant will stare fixedly in the direction of the bars (*5*), and this behavior forms the basis of our response measure (*6*). The observer, looking through the peephole, was not told the position or intensity of the bars. On each trial, the observer was required to judge the side on which the bars were located by observing the pattern of the infant's eye and head movements. If the observer performs better than chance at judging the location of the bars, it follows that the infant can see the bars. Thus, percent correct on the part of the observer was our dependent measure and above-chance values indicate that the infant sees the stimulus. When the intensity of the bars approaches that of the screen, the infant's staring behavior becomes random and the observer's performance drops to chance.

Figure 1 (top) shows the observer's percent correct in naming the position of the bars, as a function of the log relative luminance of the bars. For intensity differences of about 25 percent (0.1 log unit) and above, the observer's performance was always 90 percent or better. Of the intensities we used, only the increment of 5 percent (0.02 log unit) above the background intensity was small enough that the infants failed to stare at the bars. Under the stimulus conditions of the experiment, then, the U-shaped dip in the discrimination function—the intensity range yielding near-chance performance—is remarkably narrow. For example, the width at 65 percent correct in these data is only about 0.08 log unit (*7*).

The very sensitive brightness discrimination shown here is sufficient to raise serious doubts about previous studies claiming evidence of color vision in human infants (*2*). In those studies, if the stimuli were mismatched in brightness to the infant by only a few percent, the infants may have responded on the basis of brightness and not hue (or saturation). These data then demonstrate the need for rigorous brightness controls in color vision experiments.

Next, we altered the stimuli in a way that we hoped would reduce the infants' performance on the brightness discrimination task. The four wide white bars were replaced by a single narrow vertical white bar (8.4 by 0.6 cm, or 13.9° by 1.0°).

The data from one infant, Katrina, are shown in Fig. 1 (bottom). With the narrow bar, the bottom of the U-shaped brightness discrimination function was made a little broader. For the infant tested, the observer's performance remained at chance across at least 0.075 log unit (from -0.015 to +0.06 log unit around the matching intensity), and the width of the curve at 65 percent correct is about 0.1 log unit.

In our third experiment, we replaced the white bar with a red (Kodak Wratten No. 29; dominant λ = 633 nm) bar. As discussed above, we assume that at some intensity within ±0.4 log unit of an adult brightness match, the infant's brightness match should occur. If the infant has no color vision, her performance should drop to chance at her brightness match, and the infant should generate a U-shaped function identical to her white-bar function. Furthermore, if the infant has a brightness discrimination function like that in Fig. 1 (bottom), then exploration of the 0.8 log unit range of intensity of the red bar, in intensity steps of about 0.1 log unit or less, ought to be sufficient to find the U, if it exists. If no dip to chance performance occurs, one can conclude that the infant has color vision.

In the color vision experiment, 12 intensities of the red bar were used (*8*). They spanned the range around the adult heterochromatic brightness match in steps of 0.085 log unit or less. In addition, four intensities of white light were used, to establish the brightness discrimination function (see Fig. 1, bottom) for each individual infant.

Figure 2 shows the data from two infants. The lower graph shows the observer's percent correct with the four white stimuli. The data are very similar to those of Fig. 1 (bottom), and verify the adequacy of the 0.085 log unit step size for the red stimuli for these individual infants.

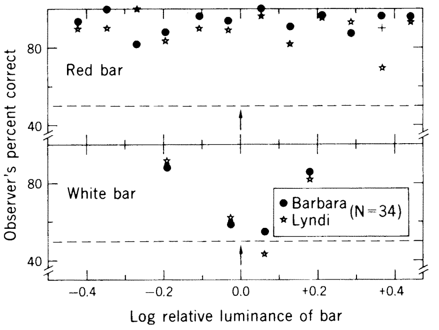

Fig. 2. (Top) Color vision in two 2-month-old human infants, Barbara and Lyndi. A red bar replaced the white bar of Fig. 1 (bottom). Zero on the abscissa indicates the log luminance of the red bar needed for a (heterochromatic) brightness match to the white screen, for two color-normal adults. The above-chance performance at all points shows that both infants could discriminate the red bar from the white screen, across a wide range of luminances. Hence both infants must have at least dichromatic color vision. For the plus mark (+), see (*9*). (Bottom) Brightness discrimination functions (as in Fig. 1, bottom), for the two infants whose color vision was tested.

The upper graph shows the data collected with the red bar. For all intensities, with both infants, the observer's percent correct remained clearly above chance (*9*). Both infants can discriminate the red bar from the white screen for all intensities tested, providing very strong evidence that these 2-month-old infants have some form of color vision.

If an organism can discriminate between *any* single pair of lights (such as a red and a white light) on the basis of a difference in wavelength composition, then the organism must have at least dichromatic color vision. It follows that at least two receptor mechanisms of differing spectral sensitivity, plus the neural circuitry necessary to compare the outputs of the two receptor types, must be functional in that organism. The data of Fig. 2 indicate that 2-month-old human infants are at least dichromatic.

If an organism can discriminate *every* wavelength of light from white light, then the organism is at least trichromatic, and must have at least three functioning receptor mechanisms. Color-normal human adults are trichromatic (*1*), as are 6-week-old macaque monkey infants (*10*). Clearly, the present data do not establish whether or not 2-month-old human infants are trichromatic. Discrimination data using wavelengths from all spectral regions will be necessary to test this question.

The present data allow us to infer that all of the neural elements necessary for at least dichromatic color vision, and for remarkably sensitive brightness discriminations, are present in 2-month-old human infants, and, conversely, that any elements of the system which are not yet present are not necessary for these visual functions.

DAVID R. PEEPLES, DAVIDA Y. TELLER
Psychology Department,
University of Washington, Seattle 98195

References and Notes

1. T. Cornsweet, *Visual Perception* (Academic Press, New York, 1970), pp. 155–267; G. Brindley, *Physiology of the Retina and Visual Pathway* (Arnold, London, ed. 2, 1970), pp. 199–259.
2. W. Chase, *J. Exp. Psychol.* **20**, 203 (1937); M. Bornstein, *J. Exp. Child Psychol.*, in pr[illegible] J. Fagan III, *Science* **183**, 973 (1974). See also W. Kessen, M. Haith, P. Salapatek, in *Carmichael's Manual of Child Psychology*, P. Mussen, Ed. (Wiley, New York, 1970), vol. 1, p. 287; B. Wooten and J. Fagan III, *Science* **187**, 275 (1975).
3. D. Trincker and I. Trincker, in *Behavior in Infancy and Early Childhood*, Y. Brackbill and G. Thompson, Eds. (Free Press, New York, 1967), p. 179; D. Teller and D. Peeples, paper presented at the spring 1974 meeting of Association for Research in Vision and Ophthalmology, Sarasota, Florida, and report in preparation; V. Dobson, thesis, Brown University (1975). For red light (about 635 nm) the latter two studies show that infants and adults differ in relative spectral sensitivity by no more than 0.15 log unit.
4. Female infants were used in all experiments to reduce the probability that a color-blind infant would be tested inadvertently. Sex and availability were our only screening criteria; no subjects were discarded. The infants were run in five to ten 1-hour daily sessions, within a 1- to 2-week period, between the 58th and 75th postnatal days.

R. Fantz, J. Ordy, M. Udelf, *J. Comp. Physiol. Psychol.* **55**, 907 (1962).

6. This forced-choice preferential-looking, or "peep and tell," technique is described fully in D. Teller *et al.*, *Vision Res.* **14**, 1433 (1974). Typically one of the authors was the observer, and the other held the infant. A naive observer was used to generate the data of Lyndi in Fig. 2, and in some instances the infant's mother held the infant. The person holding the infant could not see the stimulus display and thus could not provide cues about the position of the bar or bars. Corneal reflections of the bar or bars were not visible to the observer.
7. The brightness discrimination functions are asymmetrical, in the sense that both infants were more sensitive to small decrements than to small increments of intensity. The asymmetry occurred with all infants tested. This suggests that the infants' responses are not governed solely by the local contrast between the screen and bars—but rather by some more global aspect of the overall stimulus configuration. The asymmetry in the infants' behavior is similar to adult supra-threshold responses: there is a greater subjective brightness difference between a dim center and a bright surround than between a bright center and a dim surround [see E. Heinemann, *J. Exp. Psychol.* **50**, 89 (19[illegible] H. Wallach, *ibid.* **38**, 310 (1948)]. The infants in the first experiment reveal very high sensitivities to brightness differences. The two infants show a 67 percent correct discrimination at a 3 percent (0.015 log unit) contrast decrement, a level of sensitivity higher than that of previous reports [for example, J. Atkinson, O. Braddick, F. Braddick, *Nature (Lond.)* **247**, 403 (1974); J. Doris, M. Caspar, R. Poresky, *J. Exp. Child Psychol.* **5**, 522 (1967)]. The plus marks (+) in Fig. 1, bottom, indicate data collected during the last day's session.
8. For each day's session six intensities of the red bar and two intensities of the white bar were used. In one type of session, the leftmost and every alternate intensity in Fig. 2 (top) were used, plus the -0.19 log unit and the +0.06 log unit white intensities. In the other type of session, the remaining six red and two white intensities were used. The type of session was counterbalanced across days. Within a session, the position, color, and intensity of the bar were randomized.
9. With one of the infants, Lyndi, at one relative intensity of the red bar (+0.365 log unit) the observer's performance fell to 70.6 percent. A retesting of this value at the end of the experiment yielded a percentage of 91.2, which is indicated by the plus mark (+) in Fig. 2.
10. R. Boothe *et al.*, *Vision Res.*, in press.
11. Supported by PHS grant EY00421 to D.Y.T. and PHS postdoctoral fellowship EY04085 to D.R.P. We thank H. Lai, J. Poli, and M. Bell for laboratory assistance, and Drs. J. Schaller, V. Dobson, W. Makous, N. Weisstein, D. Yager, T. Cornsweet, and J. Fagan III for comments on the manuscript.

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